DSL
Distributed
Systems
Laboratory

ATC

Adaptive Network Architecture (ANA) – A Multi-Agent Software Framework for Heterogeneous Spacecraft

Dipa Suri and Adam Howell
dipa.suri@lmco.com
adam.howell@lmco.com

Distributed System Laboratory
Lockheed Martin Advanced Technology Center
3251 Hanover St,
Palo Alto, Ca. 94304

ESTC-2005

DSL
Distributed
Systems
Laboratory

Acronym List

ATC

- ACE – ADAPTIVE Communications Environment
- ACL – Agent Communication Language
- ANA – Adaptive Network Architecture
- CORBA – Common Object Request Broker Architecture
- DSL – Distributed Systems Laboratory
- FCE – Formation Computing Environment
- FIPA – Foundation for Intelligent Physical Agents
- FPGA – Field Programmable Gate Array
- IDL – Interface Description Language
- ISIS – Institute for Software Integrated Solutions
- PPC – PowerPC
- RTAI – Realtime Application Interface
- RTEC – Realtime Event Channel
- RTOS – Realtime Operating System
- SOW – Statement of Work
- TAO – The ACE Orb

DSL
Distributed
Systems
Laboratory

Outline

ATC

- Motivation
  - Project Description
  - Agent Definition
- Adaptive Network Architecture (ANA) Overview
  - Inter-agent Communication
  - Basic Agent Functionality
  - Agent Descriptions
- Implementation & Testing
  - Target Platform(s)
  - Example Science Mission: Gamma Ray Burst Detection
- Development Status & Future Work

Key Themes

- Satellite Formations Are Key Elements Of Earth Science Enterprises' Strategic Plan In Support Of Space And Earth Sciences Vision 2010
  - Improve Mission Performance Through Automation and Autonomy
  - Improve Performance, Flexibility and Adaptability of Data Processing
  - Improve System Interoperability and Use of Standards
  - Reduce Life Cycle Cost Of Space and Ground Based Processing

DSL Distributed Systems Laboratory

Key Themes (cont'd)

ATC

- AIST Space Investment Themes:
  - Agent Based Distributed Processing Reference Architecture for Multiple Autonomous Spacecraft
  - Distributed Processing On Multiple Spacecraft Via Satellite IP Networks
  - Distributed Computing in a Multiple Spacecraft Setting
  - Re-configurable HW For Data Processing and Distribution For Multiple Spacecraft

What is the ANA?

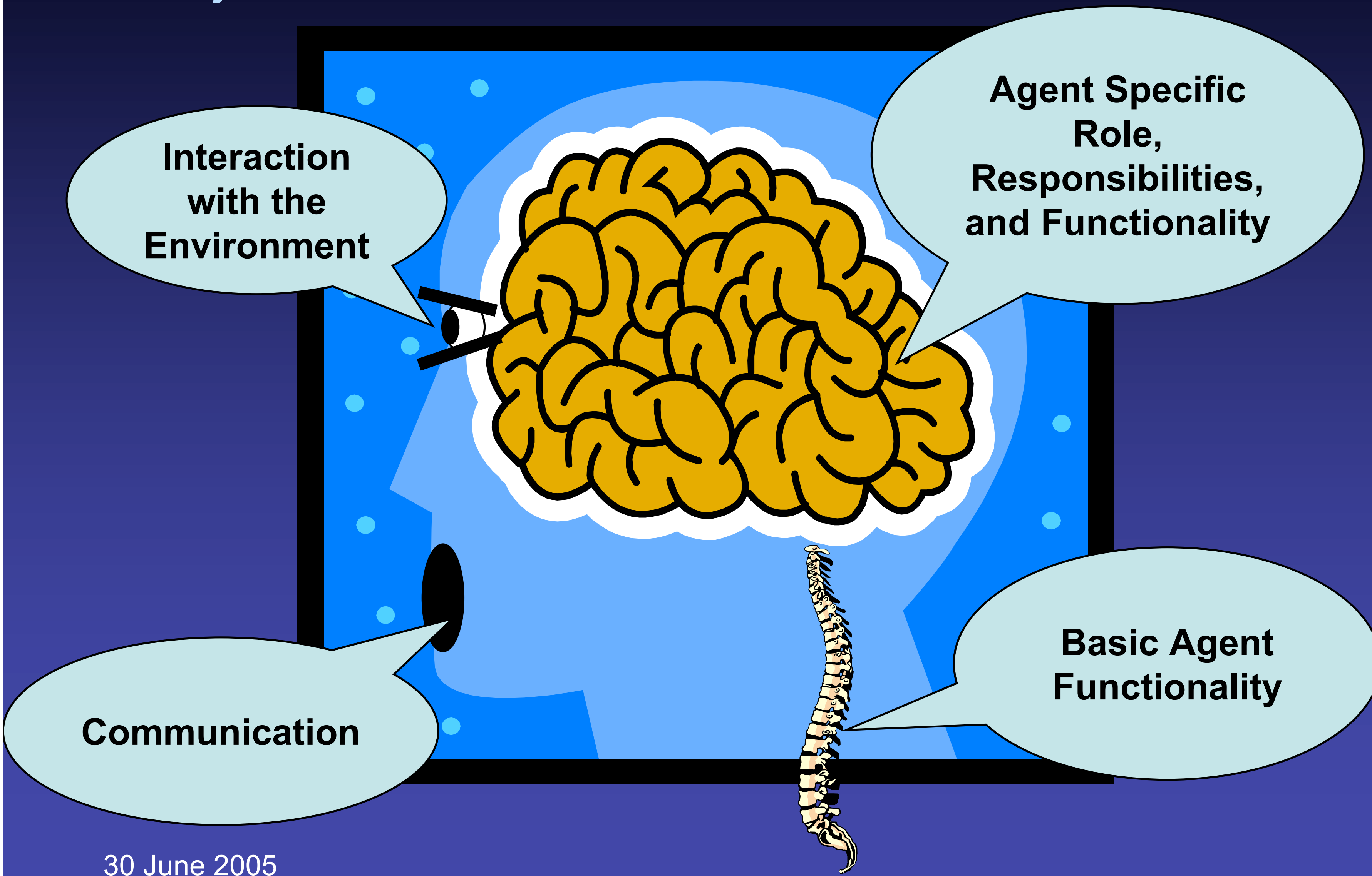
An agent based software framework that provides autonomy for science missions comprised of multiple, heterogeneous, distributed assets

- The Adaptive Network Architecture (ANA) Software is based on the concept of *Software Agents*
- Software Agents have many different definitions, but common characteristics include *Communication*, *Collaboration*, and *Autonomy*

DSL
Distributed
Systems
Laboratory

Anatomy of an ANA Agent

ATC



ANA Agent Functionality

- Phase 1 - Initial Capability
  - Distributed operation on multiple platforms
  - Collocated and remote agent communication
  - Provide real-time computing resource monitoring
  - Provide interface to “ground” user
- Phase 2 – Expanded Operational Capability
  - Resource allocation for science processing
  - Multiple sensor/user support
  - Fault management
  - Autonomous mode switching

ANA to Key ESTO & AIST Theme Mapping

DSL Distributed Systems Laboratory

ATC

Theme	ANA Characteristic	Phase Implementation
Automation/ Autonomy	Set of intelligent agents	1& 2
Flexibility, Adaptability of Data Processing	Specific roles designed into agent classes	1& 2
System Interoperability, Use of Standards	Use of ACE/TAO for interoperability CORBA & FIPA standards	1
Reduce Life Cycle Cost	By design	1 & 2
Agent Based Distributed Processing	Main design principle	1& 2
Multiple Autonomous Spacecraft	Future validation on representative testbed	2
Distributed Processing/ Satellite IP Networks	Main design objective	1 & 2

AIST funding facilitating technology extensions over 2 phases

DSL
Distributed Systems Laboratory

ANA to Key ESTO & AIST Theme Mapping (cont'd)

ATC

Theme	ANA Characteristic	Phase Implementation
Distributed Computing	**Further development of specific agent roles**	**2**
Re-configurable HW	**Potential future incorporation of FPGA technology**	**TBD**

Outline

- Motivation
  - Project Description
  - Agent Definition
- Adaptive Network Architecture (ANA) Overview
  - Inter-agent Communication
  - Basic Agent Functionality
  - Agent Descriptions
- Implementation & Testing
  - Target Platform(s)
  - Example Science Mission: Gamma Ray Burst Detection
- Development Status & Future Work

ANA Agent Anatomy Revisited

DSL
Distributed Systems Laboratory

ATC

- Communication
  - Highest level language based on FIPA Agent Communication Language (ACL)
  - Each agent class also has internal vernacular ACL
  - CORBA interfaces and services support message exchange between agents
- Basic Agent Functionality
  - Centered around messaging support, health indicators, and data exchange
  - Common immutable functionality encapsulated in an abstract BaseAgent class
- Agent Specific Roles, Responsibilities, and Functionality
  - Each agent has a specific role and set of responsibilities
  - Interaction between the agents meets the objectives of a distributed mission
- Interaction of Environment
  - Physical measurements and/or actions are currently specific to an agent

DSL
Distributed Systems Laboratory

ANA Agent Communication

ATC

- Common Object Request Broker Architecture (CORBA) provides basic building blocks for inter-agent communication through *interfaces* and *services*
- CORBA Interface Description Language (IDL) is used to describe common interfaces independent of the programming language used for implementation
- CORBA services provide additional functionality common to many applications
  - Naming service (white pages)
  - Event service (realtime messaging)
  - Notification service (messaging with extensive filtering)
  - Trading Service (yellow pages)

DSL Distributed Systems Laboratory

ANA Agent Communication (cont'd)

ATC

- The ACE ORB (TAO) CORBA distribution
  - Available at http:// **www.dre.vanderbilt.edu/TAO**
  - Developed by the Distributed Object Computing (DOC) group
  - Numerous industrial sponsors including DARPA, NASA, NSF, Boeing, Raytheon, Motorola, BAE Systems, & Lockheed-Martin

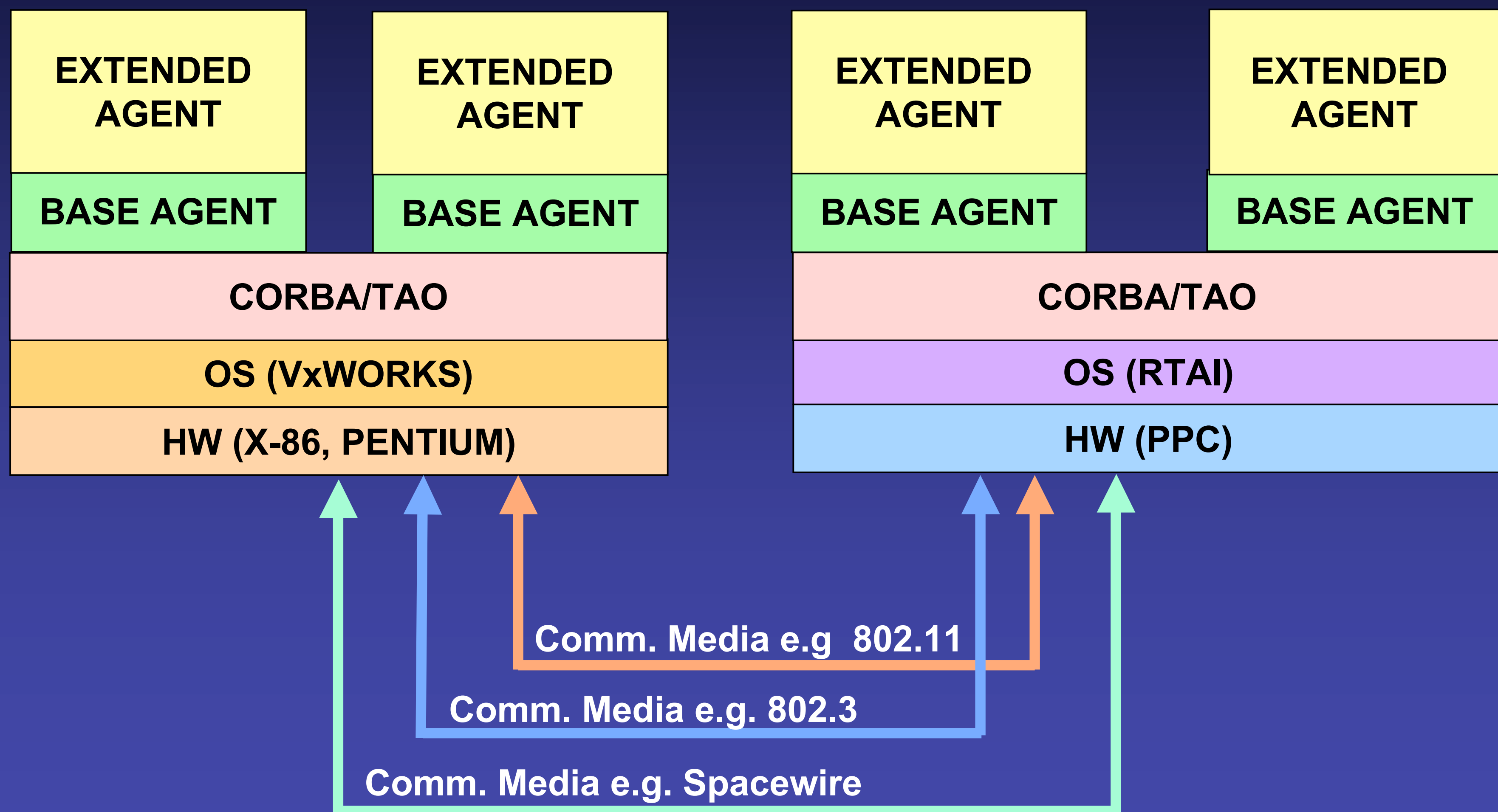
Base Agent

- Base class that provides fundamental agent functionality
- Derives from the BaseAgent interface to support standardized agent interface
- Supports common messaging format to shield derived agents from most details of specific underlying messaging service
- Capabilities
  - Regular heartbeat signal sent to receiving agent (Executive Agent) indicating agent health
  - Regular telemetry update sent to groundstation, where telemetry contents defined by derived agent class

DSL
Distributed Systems Laboratory

Distributed Agent Representation

ATC

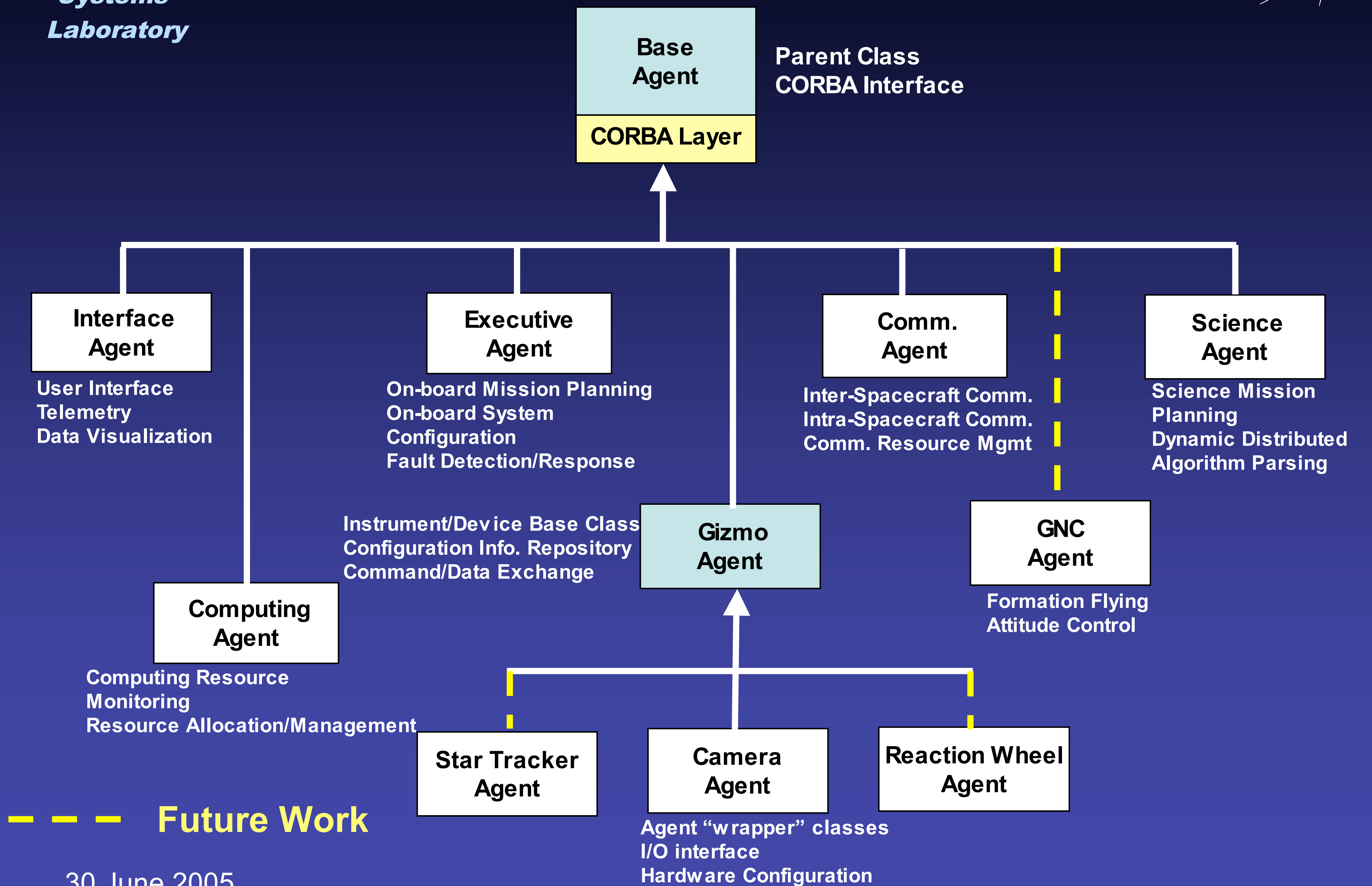


30 June 2005

DSL Distributed Systems Laboratory

ANA Class Hierarchy

ATC

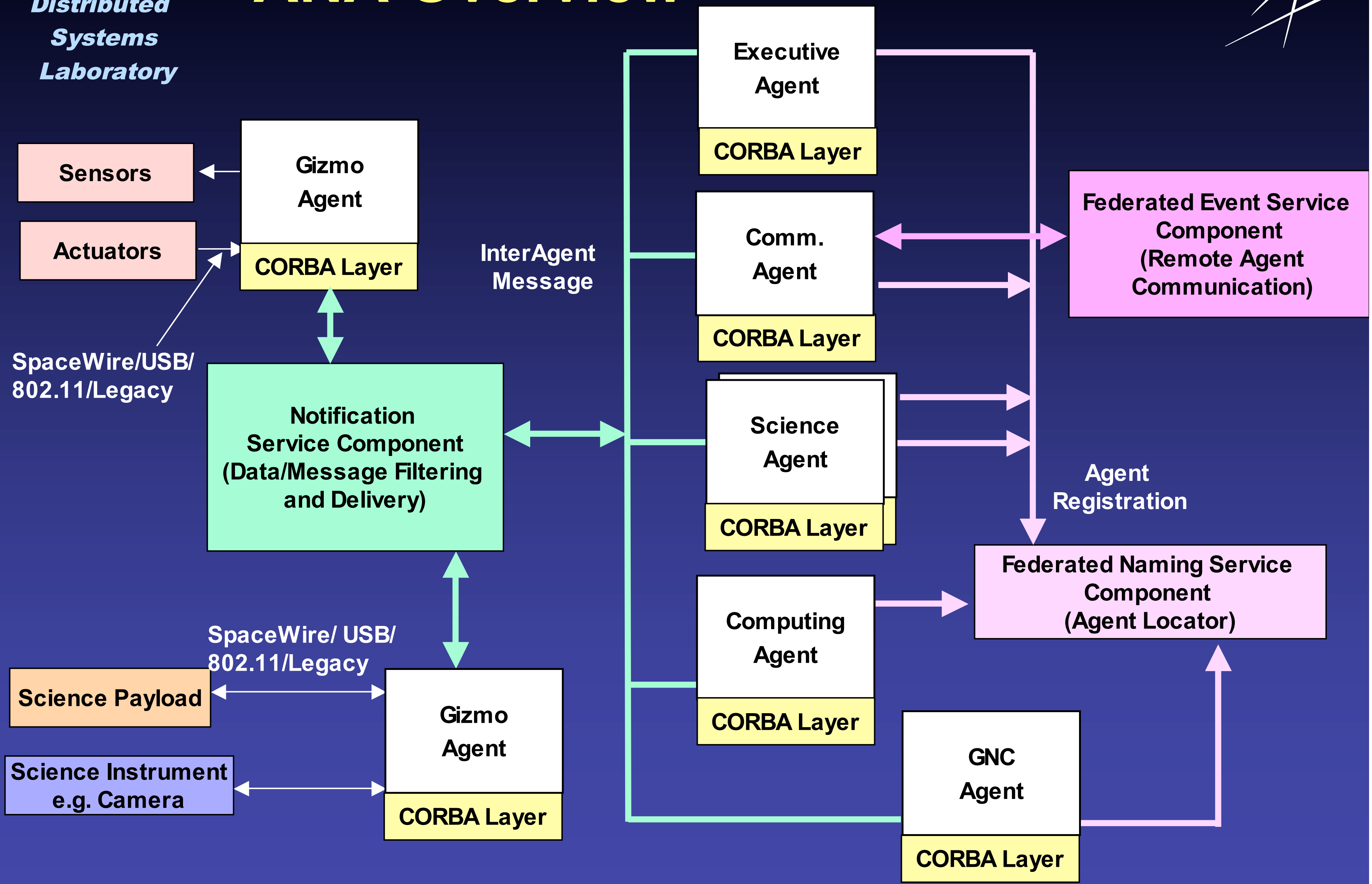


30 June 2005

DSL
Distributed Systems Laboratory

ANA Overview

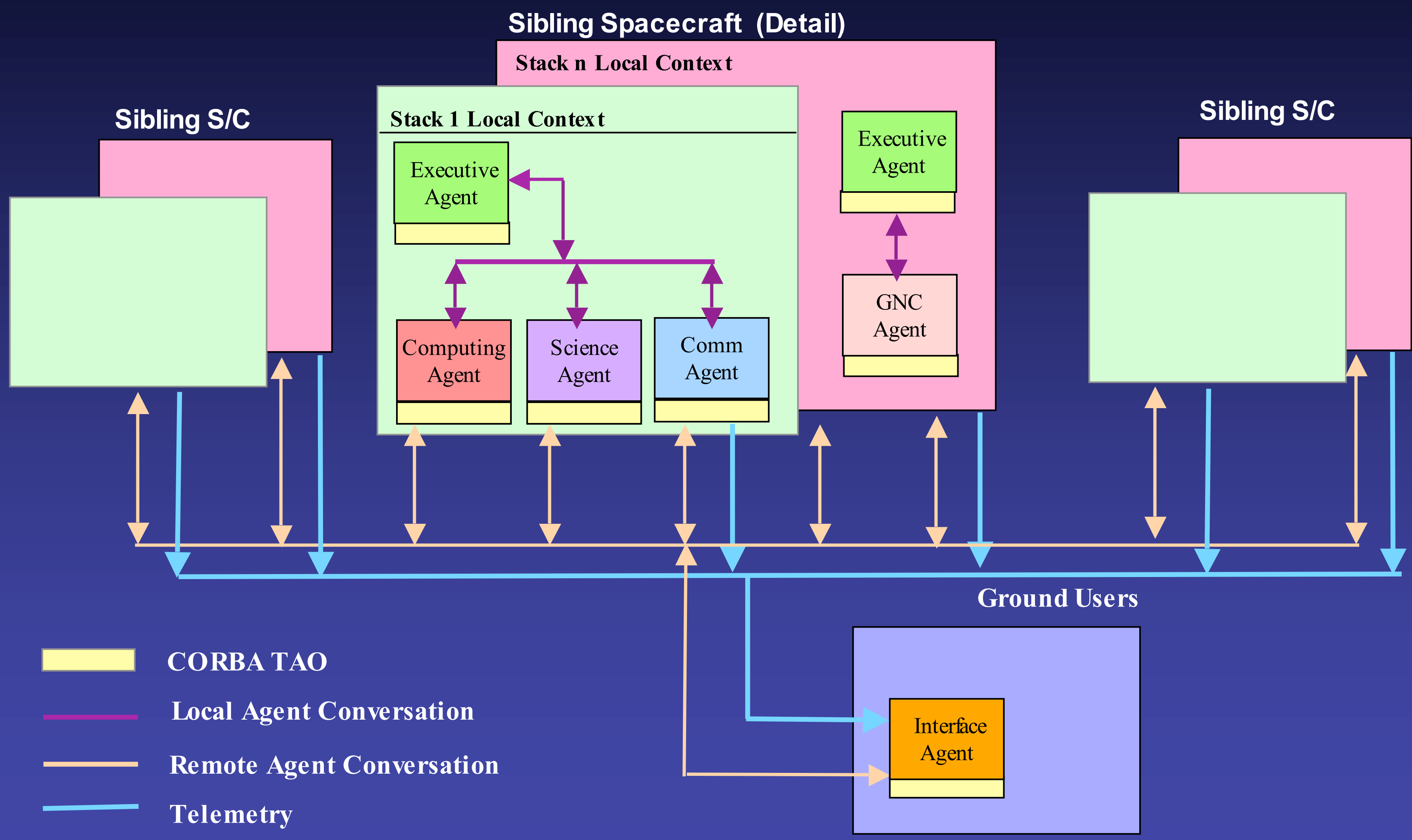
ATC



30 June 2005

DSL
Distributed Systems Laboratory

Logical Network Schematic



30 June 2005

Executive Agent

- Oversees agents on a single stack for system initialization, fault recovery, and system security
- Current Capabilities
  - Controls instantiation of new agents
  - Monitors agent heartbeat
  - Controls agent state change – autonomous or solicited
- Future Capabilities
  - Mission Planning
  - Fault Management
  - Security

DSL
Distributed
Systems
Laboratory

Computing Agent

ATC

- Monitor, allocate, and negotiate for computing resources
- Primarily manage resources for soft or non-realtime tasks, i.e. onboard data processing by the science agent
- Capabilities
  - Resource monitoring
    - CPU load
    - Memory available
    - Network throughput
  - Resource allocation
    - Adaptive load balancing across local and remote computing platforms
    - Balancing algorithm based on estimated execution time of requested task and available memory

DSL
Distributed Systems Laboratory

Science Agent

ATC

- Workhorse for science data processing and sensor management
- Contains framework for building processing pipeline from sequence of algorithms (via ACE Streams)
- Current Capabilities
  - Parallel processing
  - State Machine Logic
- Future Capabilities
  - Distributed parsing of science algorithms
  - Adaptation to changes in environment
    - Cluster formation
    - Algorithm type
    - Data rate
    - Sensor allocation

Gizmo Agent

- Provides an agent interface to “negotiable” hardware components, i.e. payload sensors
- Implemented as an abstract class to provide core capabilities, while derived classes provide component specific support
- Derived class for CMU Smart Camera completed
  - Operating modes: Color range tracking and image capture
- Capabilities
  - Implements a publish/subscribe protocol that allows subscription to data for variable durations and sample rates
  - Priority base scheduling of conflicting subscriptions

DSL
Distributed Systems Laboratory

Communication Agent

ATC

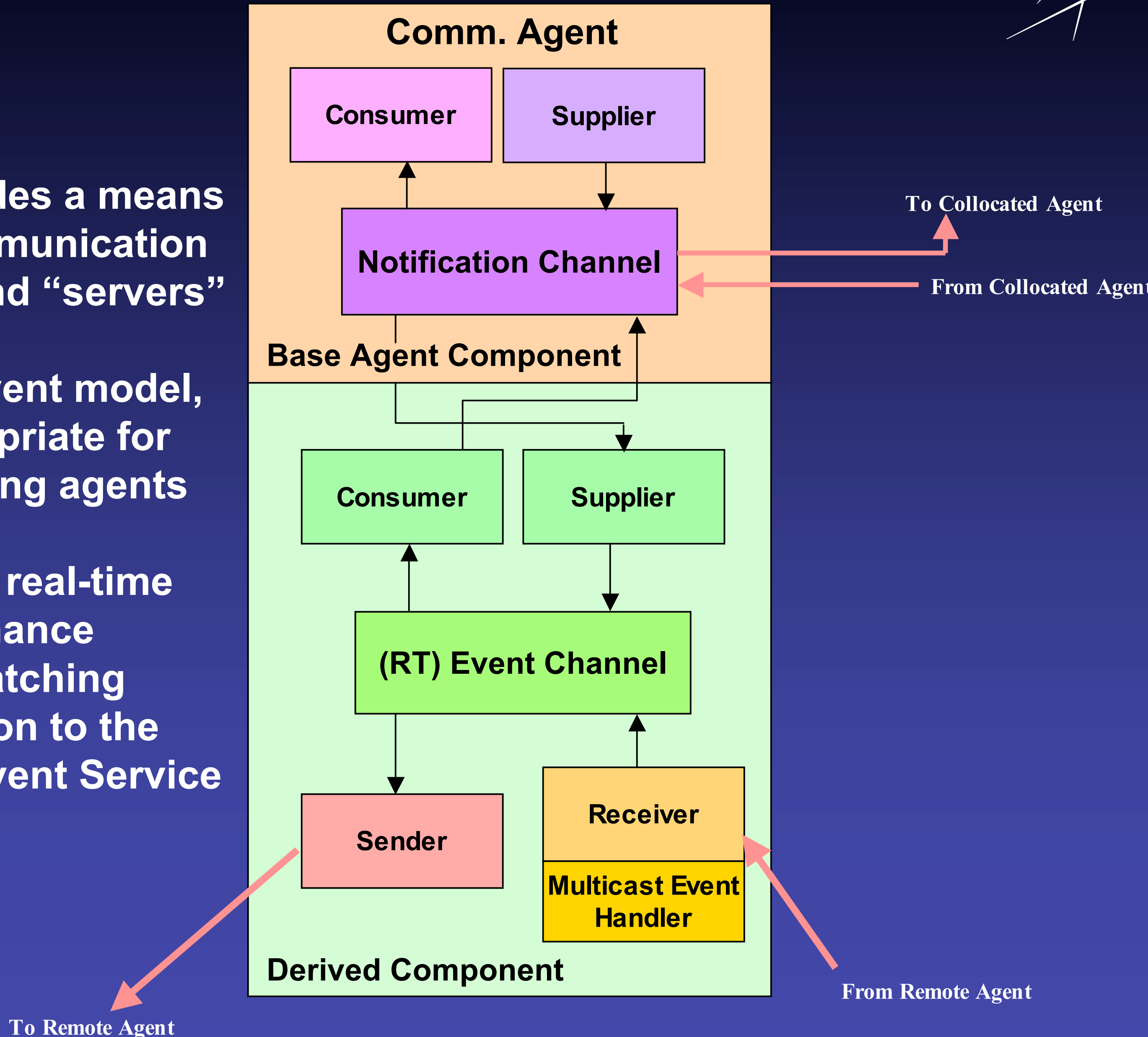
- Management of communication mechanisms between system components (e.g. processors, spacecraft, and groundstation)
- Current Capabilities
  - Service initiation to facilitate inter-agent communication (e.g. CORBA Event Service, Notification Service)
  - Telemetry packaging and transmission to ground
- Future Capabilities
  - Message logging
  - Communication resource management
    - Efficient use of links
    - Reliability of network services
    - QoS requirements

DSL
Distributed Systems Laboratory

Comm. Agent Services

ATC

- Event Service provides a means for de-coupling communication between “clients” and “servers”
- TAO uses “push” event model, which is most appropriate for the ANA’s multitasking agents
- TAO RTEC provides real-time extensions, performance optimizations, dispatching mechanism extension to the standard CORBA Event Service



DSL
Distributed Systems Laboratory

Ground Interface Agent

ATC

- Proxy between ground users and the ANA agents
- Current Capability
  - Provide visibility into “on-board” operations via telemetry processing and display
  - Provide communication with on-board agents
- Future Capability
  - User-selectable initial system configuration i.e.
    - define agent subset per spacecraft, per processor. This constitutes the “default” set to be instantiated at subsequent system start ups
    - describe the hardware signature for each agent as part of the agent’s knowledge base
    - describe the algorithm set for each agent as part of the agent’s knowledge base
  - Provide expert assistance to ground users

DSL
Distributed
Systems
Laboratory

Outline

ATC

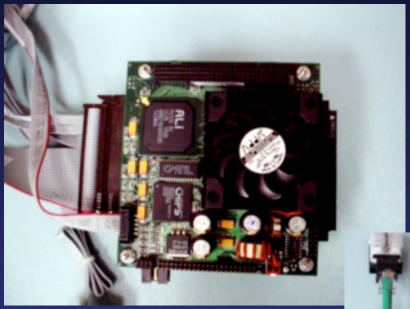
- Motivation
  - Project Description
  - Agent Definition
- Adaptive Network Architecture (ANA) Overview
  - Inter-agent Communication
  - Basic Agent Functionality
  - Agent Descriptions
- Implementation & Testing
  - Target Platform(s)
  - Example Science Mission: Gamma Ray Burst Detection
- Development Status & Future Work

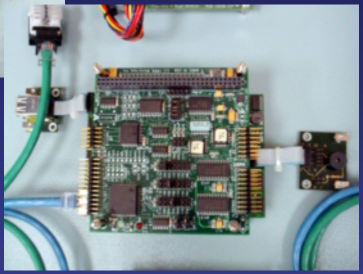
DSL
Distributed
Systems
Laboratory

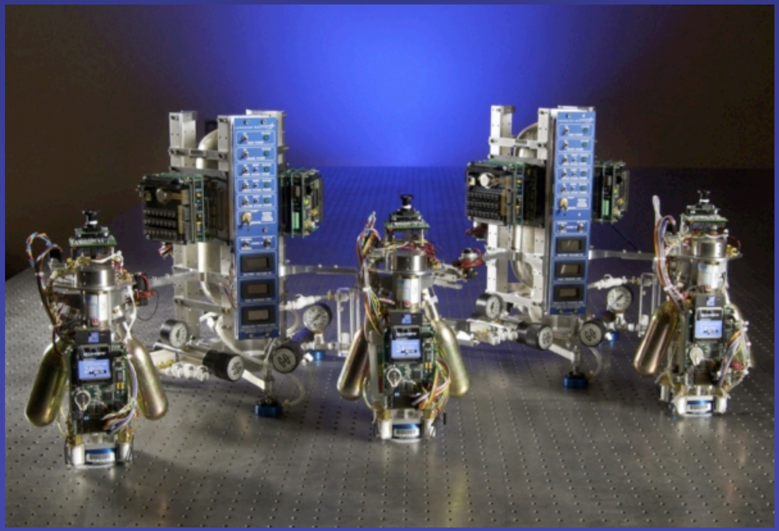
Testing the ANA

ATC

- Implementation and validation of the ANA is being conducted on the Formation Computing Environment (FCE)
- The FCE is being developed under existing IRAD funds in the Distributed Systems Laboratory (DSL)
- The FCE consists of
  - Heterogeneous computing platforms (e.g. PC/104 “stacks”)
  - Two classes of robotic assets representative of small spacecraft (Micro and Picobots)







DSL
Distributed
Systems
Laboratory

Testing the ANA (cont'd)

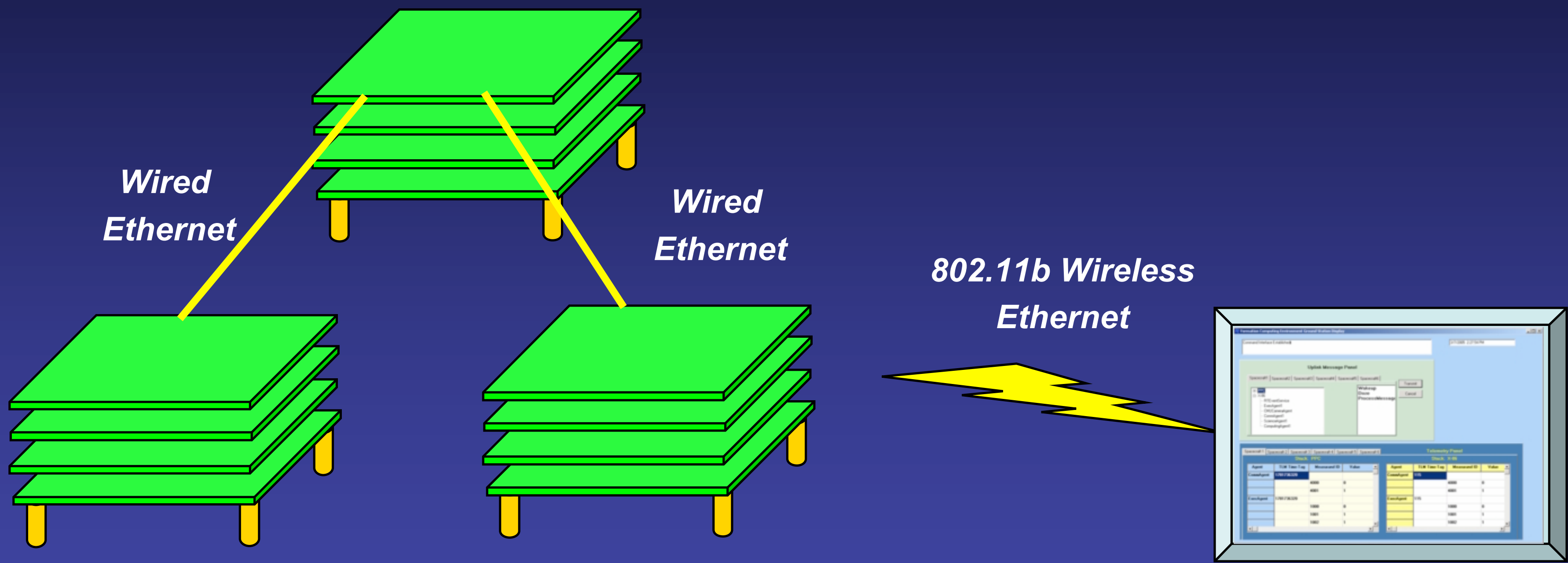
ATC

- The FCE is inherently heterogeneous in terms of
  - Computational assets
    - Potentially 3 different processor types on each Microbot (Pentium, PPC, FPGA)
    - Different form factor processor on Picobots (486 SBC)
    - 2 different operating systems (VxWorks, Linux)
  - Spacecraft and Payload hardware
    - Differences in actuation and sensing (e.g. reaction wheels, thrusters, cameras)
    - Microbots are designed for support of a wide range of payload sensors (within physical limitations)
- Development of the FCE is currently ongoing

DSL Distributed Systems Laboratory

FCE System Architecture for a single Microbot

ATC

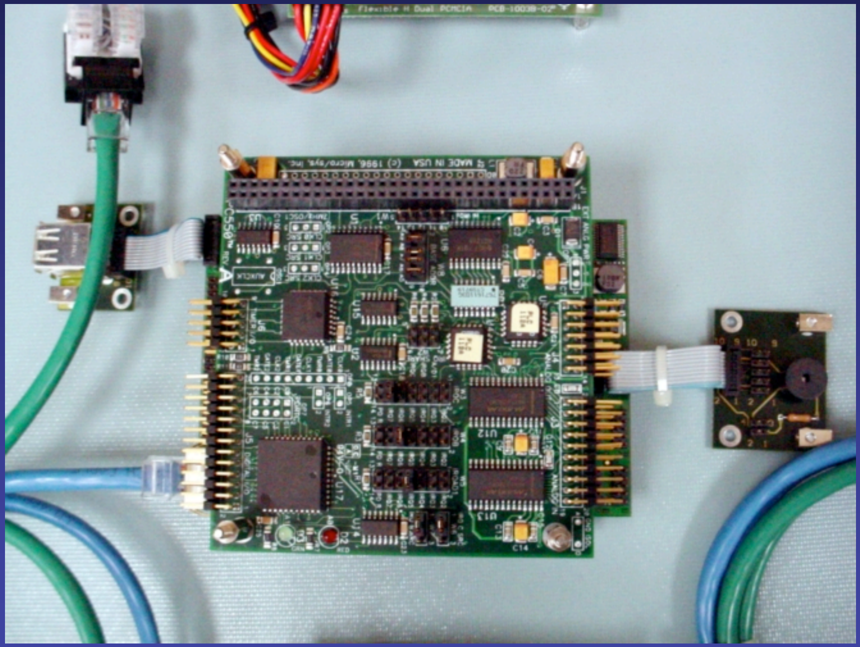


DSL
Distributed
Systems
Laboratory

FCE Hardware Testbed – Mixed RT Environment

ATC

- Combination of hard and soft realtime tasks
  - Data acquisition = hard
  - Data processing = soft
- Some direct hardware interface for sensor data acquisition & control
- Scalable prioritization of processing tasks between hard, soft, and non realtime support
- GNU Linux OS with RTAI realtime extensions
- PC/104 stack specs
  - PowerPC (MIP 405) processor
  - CompactFlash Nonvolatile Storage
  - One Data Acquisition Board (MPC 550)
  - DC/DC power supply

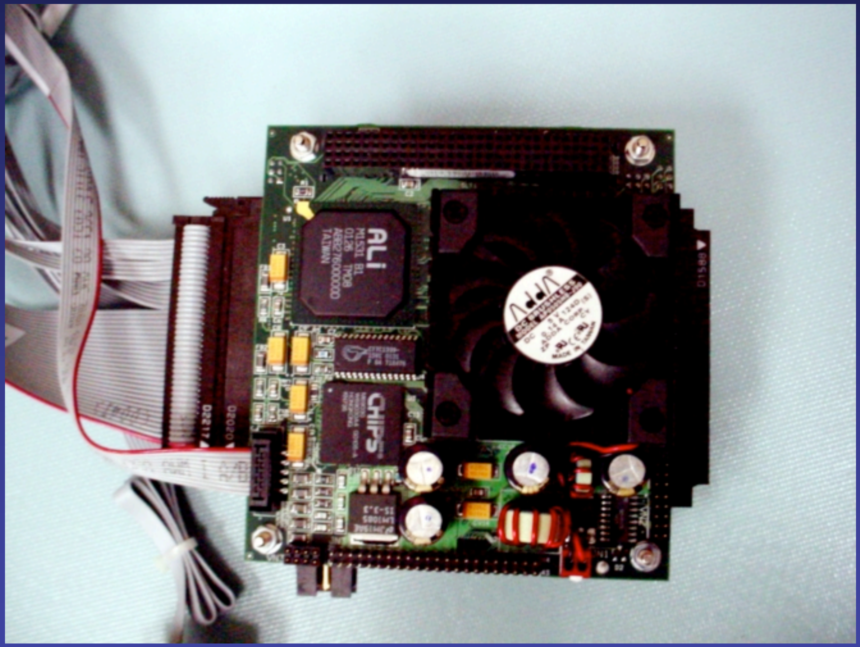


DSL
Distributed
Systems
Laboratory

FCE Hardware Testbed – Hard RT Environment

ATC

- Strict hard realtime constraints
- Primarily for direct hardware interface and high fidelity control
  - Spacecraft attitude control
  - Mission-specific processing & control
- VxWorks RTOS
- PC/104 stack specs
  - Intel Pentium III processor
  - DiskOnChip (DOC) Nonvolatile Storage
  - Two data acquisition Boards (MPC 550)
  - DC/DC power supply



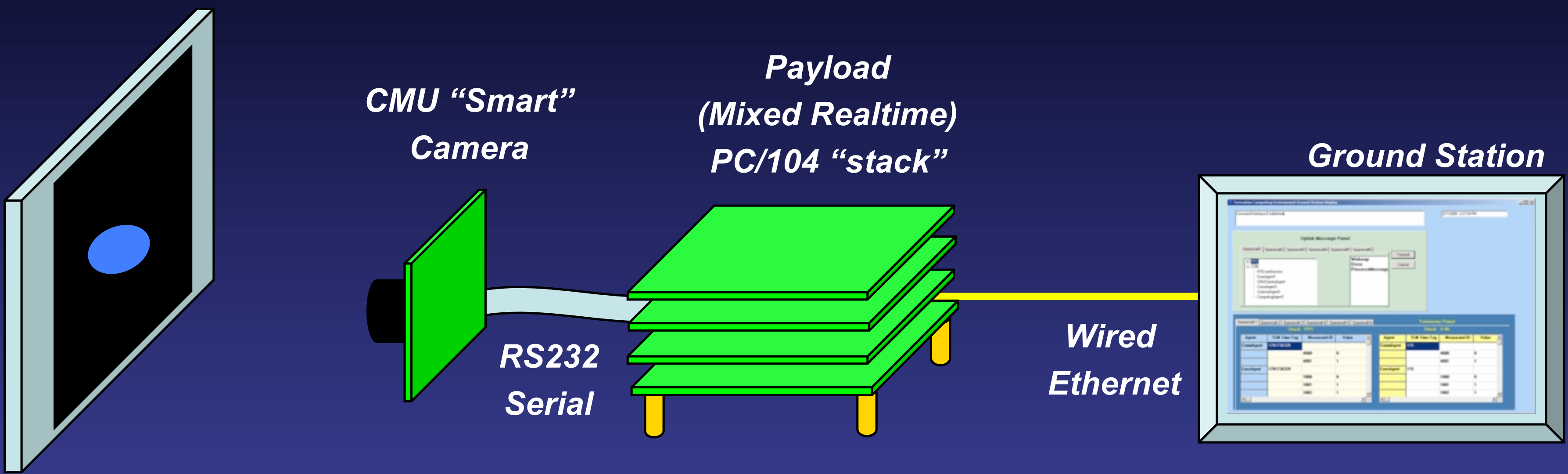
DSL
Distributed
Systems
Laboratory

Development Tools

ATC

Tool	Description	Version
VxWorks / Tornado	Real-Time Operating System, X-86 stack	5.5 / 2.2
Linux/RTAI	O.S. PPC stack	LFS using 2.4 kernel
Windows NT	Ground Station O.S.	
Borland C++ Builder	Development Environment, Ground Station	6.0
TAO (Stacks)	CORBA	OCI_1.3_p11
TAO (Ground)	CORBA	DOC Group 1.3
Subversion	Version Control	1.1

Example Science Mission - Gamma Ray Burst Detection



- Mission objective:

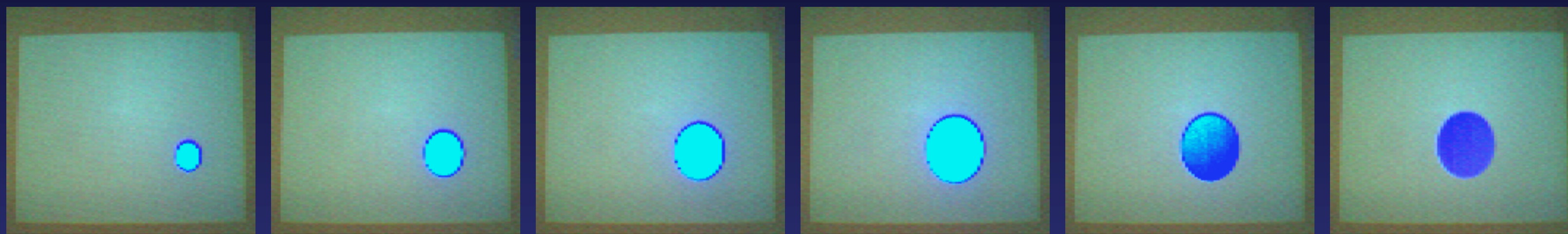
  Detect and image transient gamma ray burst events
- Full ANA on Payload Stack but primarily exercises Gizmo, Science, and Communication agents
- Imaging and telemetry are downlinked to Interface Agent on Ground Station

Gamma Ray Burst Mission Logic

- System Initialization
- Science Agent requests subscription for CMU Camera to track specific color range at max sample rate
- As a burst occurs, CMU Camera notifies Science Agent once detected
- Science Agent requests a change in subscription for CMU Camera to capture an image
- Once image capture complete, CMU Camera relays image to Science Agent for post processing and telemetry packaging (eg. compression & save to file)
- Science Agent requests a change in subscription for CMU Camera to return to burst detection mode

DSL
Distributed Systems Laboratory

Representative Results



- Simulated burst properties
  - Random initial location within FOV and random inter-burst delay
  - Ten second burst duration
  - Varying intensity over a single burst event
- General comments
  - Software configuration straightforward
    - Two state Finite State Machine for science mission logic
    - Default ANA setup handles majority of necessary system configuration
  - Reasonable data acquisition within limits of CMU camera performance
    - Slow maximum sample rate for image capture (~ 1 FPS!)
    - Sensitivity to color range

Outline

- Motivation
  - Project Description
  - Agent Definition
- Adaptive Network Architecture (ANA) Overview
  - Inter-agent Communication
  - Basic Agent Functionality
  - Agent Descriptions
- Implementation & Testing
  - Target Platform(s)
  - Example Science Mission: Gamma Ray Burst Detection
- Development Status & Future Work

DSL
Distributed Systems Laboratory

Development Status

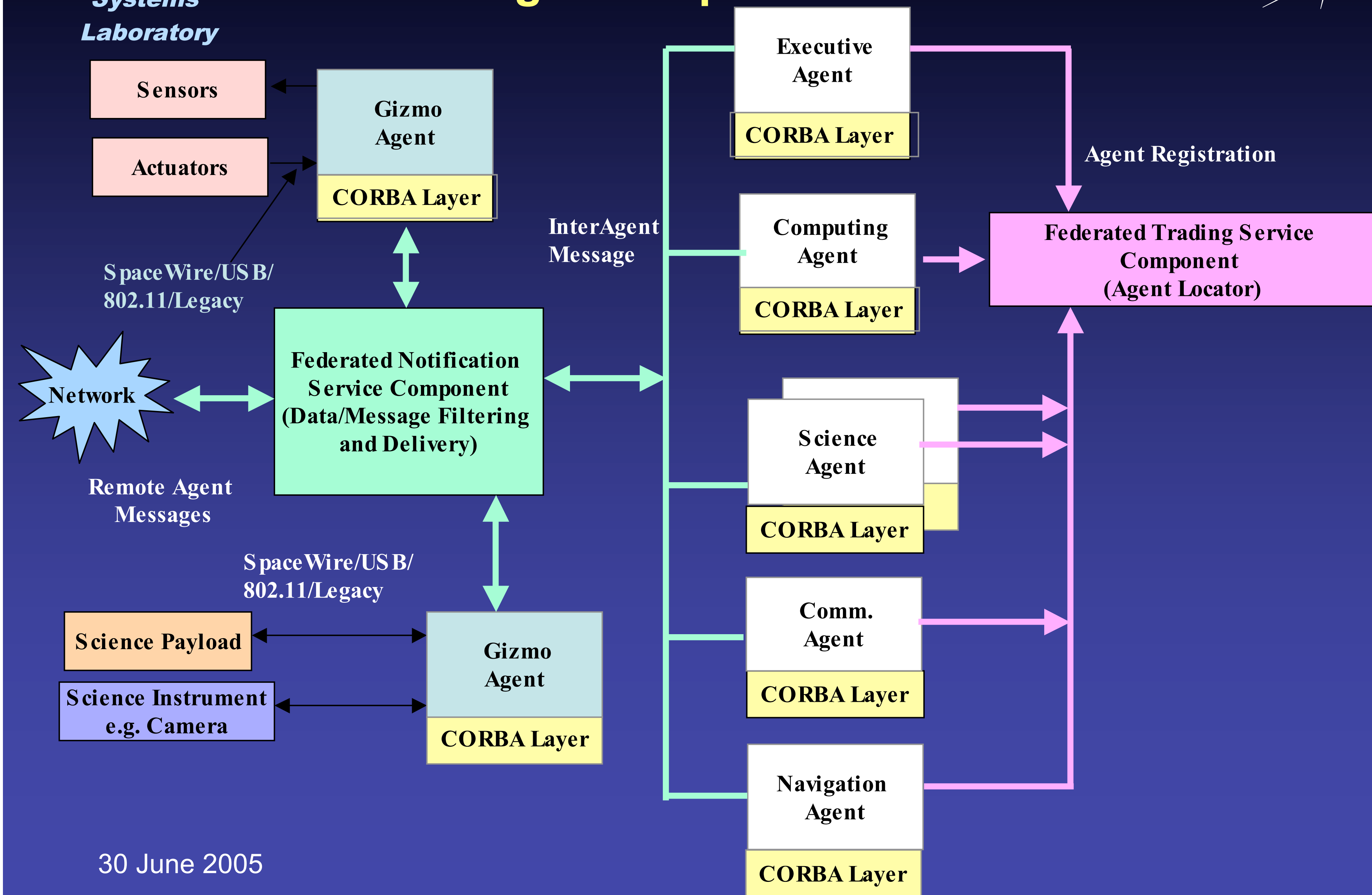
ATC

- ANA framework in place
- Agent Base Class definition complete and implementation verified on both processing environments
- Basic capability of Computing, Science, Gizmo, and Communication agents verified on both processing environments
  - Agents generate heartbeat at specified periodicity
  - Agent communication between collocated agents verified for heartbeat messages (uses the ANA ACL)
  - Agent communication between remote agents verified
- Ground interface agent successfully communicates with remote agents on virtual spacecraft
- Example science mission to demonstrate capabilities

ANA Future Enhancements

- Integration of ongoing ACE/TAO/CIAO improvements
- Agent interaction in a multi-spacecraft environment via 802.11b
- Full science algorithm adaptation and data processing for a representative science mission (eg. Leonardo-BRDF or MMS)
- Simple cognitive behavior of agents
  - "Higher" level reasoning such as
    - More complex science missions
    - On-line evaluation of performance
    - Adaptation to varying conditions
  - System reconfiguration in response changes in
    - Resource availability (predictable and unpredictable)
    - Science mission objectives
- Improved user interface for ground station interaction

ANA Schematic for a Single Computational Node



30 June 2005

Acknowledgements

Thank you AIST and ESTO!